STATUS OF THE CORAL REEFS OF PUERTO RICO

Cruz A. Matos, Jorge R. García, and Ernesto Díaz

Introduction

The Commonwealth of Puerto Rico is approximately 1,600 km from Miami and lies between the island of Hispaniola and the US Virgin Islands. These islands – the main island of Puerto Rico and five smaller islands – are the smallest and eastern-most in the Greater Antilles. They have a combined land area of about 8,897 km^2 and a linear coastline of 620 km. Two of the small islands off the eastern coast of the main island are inhabited (Culebra and Vieques); the three islands off the western coast are not (Mona, Monito, Desecheo).

The island of Puerto Rico is almost rectangular (56.3 km by 161 km) with a mountainous interior formed by a central mountain chain (covering 60%), extending east to west across the island. The main island has coral growth along much of the insular shelf, but reef development is mostly restricted to the eastern, southern, and western coasts as a result of physical, climatic, and oceanic conditions.

With the exception of Monito Island, NOAA recently mapped Puerto Rico's coral reef ecosystem and associated habitats (e.g., sand, hardbottom, algae, mangroves) to a depth of about 20 m, and delineated a total coral reef ecosystem area of 5,009.6 km^2 (Kendall *et al.* 2001). Coral reef and colonized hardbottom habitat comprised 756.2 km^2 (15.1%) of the total area, seagrass habitat covered 624.8 km^2 (12.5%), macro-algal dominated areas covered 96.7 km^2 (1.9%), and the mangrove fringe covered 72.6 km^2 (1.4%).

Figure 166. Detail of a spur-and-groove formation (Photo: Matt Kendall).

Puerto Rico, Culebra, and Vieques are nearly completely ringed with reefs. Submerged hard-substrate rock reefs are found on the northwestern and western coast of Puerto Rico with moderate to high topographic relief and high cover of turf algae and patchy coral growth. Flat eolianite reefs (rock formed on land by cementation of calcareous dune sands), are mostly along the northern coast of Puerto Rico with high cover of turf algae, sponges, and isolated encrusting corals. Fringing reefs are found mainly in the eastern, southern, and western coasts of Puerto Rico, Culebra, and Vieques. Northern fringing reefs are characterized by shallow (1-3 m) back-reef communities dominated by finger coral *Porites porites* and scattered coral colonies of different species.

Shelf-edge reefs are the best-developed but least studied coral reef ecosystems in Puerto Rico. An extensive reef formation is found at the shelf-edge off the southern coast, from Guayanilla to Cabo Rojo. This displays a typical spur-and-groove pattern with sand channels cutting through the shelf perpendicular to the coastline (Fig. 166). Off La Parguera, the reef starts at 18 m and continues down the shelf slope to at least 35 m. Optimal reef development can be found at 20 m at the shelf-break.

Some of Puerto Rico's best developed shelf-edge reefs are found off the western and southwestern sections of Desecheo and Mona Islands. Both of these systems are perhaps fringing reefs that extend all the way to the shelf-edge due to the small extension of the insular shelf in these oceanic islands. The waters that surround these oceanic reefs receive minimal terrigenous inputs.

Patch reefs are relatively small, submerged coral reef systems surrounded by soft sediments. These are poorly known due to their small size and thus, are excluded from nautical charts. Nevertheless, these small patch reefs may be significant due to their high abundance in some places (Fig. 167),

such as La Parguera, Cordillera de Fajardo, Mayagüez Bay, Guayanilla Bay, Mona Island, Rincon, and Aguadilla.

Coral cover generally increases with distance from shore with 10-50% live coral at shelf-edge reefs (Morelock *et al.* 2001). At shelf-edge sites on the reef platform, boulder star corals dominate at 3-15 m, with colonies up to 5 m in height; living coral extends to at least 40 m (Bruckner 1999, J. Morelock pers. comm.).

Figure 167. Patch reef (Photo: Matt Kendall).

Figure 168. Desecheo National Wildlife Refuge (Photo: USFWS).

Desecheo Island off the western coast is managed by the USFWS as a National Wildlife Refuge (Fig. 168). This has well-developed coral reefs to the south and southwest. Surveys conducted between 1997 and 1999 found live coral cover at four reef sites ranged from 38-48%, soft coral cover from 1-10%, and algal cover from 24-28 %. A high incidence of bleaching (13-29%) was noted during January 1999 surveys. Also at that time, 17% of the corals on Candlesticks Reef were diseased (Reef Keeper International summer 1999).

Mona Island, a small, uninhabited island located within Mona Passage, lies 73 km to the west of Puerto Rico and 65 km east of the Dominican Republic. The emergent lands are managed by the DNER as a Natural Reserve. This island forms the top of an underwater ridge separating the Caribbean Basin from the Atlantic Ocean; the narrow insular platform drops rapidly into deep water (366-1,159 m).

There are extensive, well-developed reefs off the western, southern, and eastern coasts of Mona. The best-developed reefs are on the southwestern coast, near the edge of the insular shelf where coral cover ranges from 10-45% and is dominated by massive boulder star corals and boulder brain corals. The southeastern coast has a narrow back reef and a well-developed reef crest dominated by elkhorn coral and symmetrical brain coral (*Diploria strigosa)*. Deeper environments are mostly hard ground with isolated corals (A. Bruckner unpub. data).

Condition of Coral Reefs

Without long-term monitoring data, it is difficult to generalize reef conditions in Puerto Rico. Lacking baseline data on live coral cover, overgrowth by algae and other biota encrusting coral skeletons has been used to indicate reef degradation.

Coral – Overall, 93 coral taxa, including 43 scleractinian corals, 42 octocorals, 4 antipatharians, and 4 hydrocorals have been reported from Puerto Rico (A. Bruckner pers. comm.).

Reefs ringing the main island are threatened and at places degraded, primarily because of their proximity to coastal development. Coral reefs off Puerto Rico near La Parguera, Desecheo Island, and Vieques Island have the highest abundance and cover of living coral. But these reefs have also been degraded by human and natural impacts.

Figure 169. Coral damaged by coral-livorous snails (Photo: Margaret Miller).

Recent studies of the coastal waters of Descheo indicate that these coral reefs are probably the best-developed and healthiest in Puerto Rico, with about

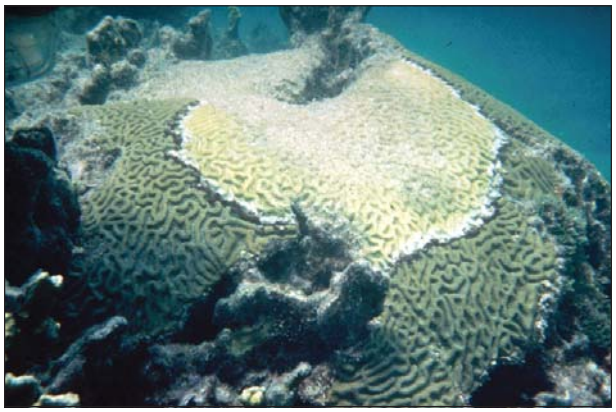
Figure 170. Today, few elkhorn coral thickets remain in Puerto Rico (Photo: Matt Kendall).

70% coral cover and high water clarity (Armstrong *et al.* 2001).

Staghorn and elkhorn coral populations have declined in most locations over the last 25 years from hurricane damage, white-band disease, and corallivorous mollusks (Fig. 169, Goenaga 1991, Bruckner *et al.* 1997, Williams *et al.* 2000). Vast stretches of elkhorn coral on the eastern coast of Puerto Rico, which appeared healthy in 1979, have been decimated possibly as a consequence of white-band disease (Goenaga and Boulon 1992). Extensive thickets of elkhorn coral formerly dominated shallow reef habitats (0-5 m). A few outer reefs still had extensive thickets as recently as 1998 (Fig. 170), but hurricane Georges heavily damaged these so that now only one thicket remains between Margarita and San Cristobel (Morelock *et al.* 2001).

Flourishing stands of staghorn coral can be found in shallow back-reef sites off San Cristobel; this species has recovered considerably since Hurricane Georges on Mario reef although white-band disease is prevalent. Isolated colonies of staghorn coral occur at 5-15 m on outer reefs and at 18-20 m on shelf-edge reefs (Bruckner unpub. data). Dense thickets still exist in areas that have been affected by disease for over seven years (Fig. 171, A. Bruckner unpub. data).

Figure 172. Black-band disease on a boulder brain coral (Photo: E.C. Peters).



Several hurricanes and white-band disease are also responsible for large losses of staghorn coral during the 1980s and early 1990s near La Parguera. These populations have continued to decline from disease, increased predation pressure by corallivorous mollusks, and Hurricane Georges (Bruckner *et al.* 1997, Morelock *et al.* 2001). White-band disease is also prevalent among elkhorn coral colonies off La Parguera, with up to 10% of the population affected at any given time.

Figure 171. Despite disease and hurricane damage, staghorn coral thickets still occur in many areas (Photo: NCRI).

Several large stands of staghorn coral and yellow pencil coral (*Madracis mirabilis*) formerly existed on Mona Island in 6-15 m, but were destroyed by Hurricane Georges, and little recovery has been noted as of August 2001.

Disease has taken its toll. white-band disease, yellow-blotch disease, white plague II, black-band disease, white plague, and seafan fungus have all affected the coral.

Black-band disease was first observed in Puerto Rico in 1972 but the incidence of disease since then has not been as prevalent as elsewhere (Fig. 172, Antonius 1981, Peters 1984). Bruckner (1999) monitored disease prevalence on reefs off the northwestern (Jobos/Isabel), western (Rincon), and southwestern coast (La Parguera) between 1994-1998, and identified several reefs with outbreaks of black-band disease. Disease occurrence varied

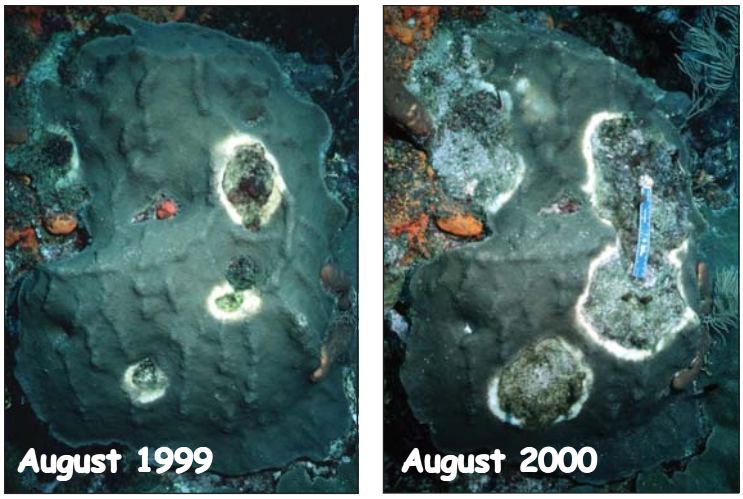


Figure 173. Progression of yellow-blotch disease over a one-year period on a mountainous star coral on Mona Island (Photo: Andy Bruckner).

seasonally and with depth on individual reefs, but infected corals were identified on near-shore reefs as well as offshore shelf-edge sites to 30 m.

White plague type II emerged on reefs of Puerto Rico shortly after Hurricane Hortense (1996), and spread to more than 50% of the brain coral population on one inner reef near La Parguera (Bruckner and Bruckner 1997). White plague has been observed on most other reefs in La Parguera, and also near Mona Island since 1999, but disease prevalence has remained fairly low (Bruckner unpub. obs.).

Yellow-blotch disease was discovered on reefs off Mona Island and Desecheo in 1996, and on two reefs near La Parguera in 1997, but few colonies were affected. By 1999, however, surveys on reefs off the western coast of Mona revealed that up to 50% of the massive boulder star corals were infected with yellow-blotch disease, and the disease was found on all other reefs examined near Mona (Fig. 173, Bruckner and Bruckner 2000).

Algae and Higher Marine Plants – First noted in the 1970s (Mckenzie and Benton 1972, Vicente 1978), the massive macroalgal cover on some near-shore reefs off Puerto Rico continues to be a source of coral mortality. For many of those reefs, the overgrowth of macroalgae is indicative of eutrophication and a result of high nutrient loads from sewage and urban outfalls.

There are extensive seagrass beds in the shallow waters around nearshore and inner reefs of Puerto Rico (Fig. 174). Mangroves fringe the southern coast of Puerto Rico and elsewhere.

Large Mobile Invertebrates – As taxonomic inventories are conducted of Puerto Rico's coral reef ecosystem over the next several years, the total number of species should be much increased. Surveys conducted between 1985 and 1999 monitored a total of 25 species of motile megabenthic invertebrates, representing five different phyla on 40 reefs and 17 seagrass/algal bed habitats (J. Garcia pers. comm.). Twelve additional reefs from four sites have been surveyed during 2000, as part of Puerto Rico DNER's coral reef monitoring program.

Five invertebrate species were identified by R. García (pers. comm.) from six different reefs – the spotted spiny and Caribbean spiny lobsters (*Panulirus guttatus* and *P. argus*), and the slate, rock-boring and long-spined sea urchins (*Eucidaris tribuloides, Echinometra lucunter* and *Diadema antillarum*). In seagrass habitats, the slate sea-urchin and the Caribbean vase (*Vasum muricatum*) were the most commonly found.

In 1983-1984, 90-95% of the long-spined sea urchin, were killed by a suspected water-borne pathogen. Vicente and Goenaga (1984) reported the mass mortality around the coastline of the main island and provided a general description of dying specimens from field observations. The loss of herbivorous urchins altered reef habitats, as thick mats of fleshy and filamentous macroalgae covered the reefs, resulting in declines of coral species, crustose coralline algal covers and clionid sponges.

Figure 174. A seagrass bed in Puerto Rico (Photo: Matt Kendall).

The urchins have since reappeared but the population is now only around a tenth of its original abundance.

Recently, researchers have expressed concern over large populations of the encrusting sponge (*Cliona* spp.) colonizing much of the exposed substrates formerly dominated by elkhorn coral. These sponges have also overgrown many other species of corals near La Parguera, Mona Island, and elsewhere (Williams *et al.* 1999, Bruckner and Bruckner in press, E. Weil pers. comm.).

Fish and Fisheries – Although no marine species are endemic to Puerto Rico, FishBase (2002) lists 242 reef-associated fish species. A total of 158 diurnal, non-cryptic fish have been identified from shallow reef and seagrass habitats during surveys off Puerto Rico (J. García pers. obs.). Preliminary analysis shows a positive correlation between fish species diversity, abundance, and live coral cover in shallow reefs (Fig. 175). The data is now being analyzed to describe the dominant populations from shallow reefs (1-10 m), deep reefs (11-25 m), rock reefs, hardbottom, and seagrass/algal beds.

Figure 175. A group of abundant blue tangs on a shallow reef (Photo credit: Matt Kendall).

Figure 176. The damage done to the coral in the upper left-hand corner was caused by bites from a territorial three-spot damselfish (Photos: Margaret Miller and J.E. Randall, FishBase).

Reef fisheries have plummeted during the last two decades, and show the classic signs of overfishing: reduced total landings, declining catch per unit effort, shifts to smaller fish, and recruitment failures. Fish landings reported between 1979 and 1990 fell 69%. (Appledoorn *et al.* 1992).

The decline in large fish and the massive die-off of the long-spined sea urchin may have caused a major shift in the community structure of many Puerto Rico reefs from coral- to algae-dominated communities. Additionally, the lack of herbivores such as parrotfishes and large fish predators has stimulated a proliferation of small fish. Damselfish (*Stegastes planifrons*), in particular, harm reefs because they bite and kill coral polyps to promote algae growth for their young (Fig. 176). This has been confirmed through the coral reef characterizations and subsequent monitoring activities in the Natural Reserves (García-Sais *et al.* 1999-2001 unpub. data, E. Hernández and R. Nemeth pers. obs.).

Persistent and increasing fishing of the spiny lobster (*Panulirus argus*) has substantially reduced this predator in shallow reefs. Consequently, there has been a proliferation of one of its favorite prey, the corallivorous gastropods in this area.

Water Quality – High sedimentation, turbidity, and nutrient loading have been associated with coral reef degradation in a number of reef systems off Puerto Rico by different authors (García *et al*. 1985, Acevedo and Morelock 1988, Castro and García 1996, García and Castro 1997, Hernández-Delgado 1995). In their qualitative inventory of reefs, Goenaga and Cintrón (1979) noted high sedimentation affected reefs along the northern coast as well as those along the southern and western coasts in bays used for ocean cargo (e.g., Guayanilla, Mayagüez).

Fringing, patch, and shelf-edge reefs off the southern coast of the main island have been degraded by high sediment influx, turbidity, and generally have lower numbers of living coral cover than those observed off Parguera. Acevedo and Morelock (1988) provided a quantitative assessment of sediment impact on southern coast coral reefs by measuring reductions of live coral cover from reefs in areas located close to sediment sources. Dead and dying coral were identified off Mayagüez, Guayanilla, and Ponce especially in areas impacted by dredging activities, sewage outfalls, industrial

discharge, ship traffic, and river discharge.

Capacity of Coastal Miles to Support Aquatic Life			
Fully supporting	Fully supporting, but threatened	Partially supporting	Not supporting
357.7 (65%)	179.5 (32.7%)	3.0 (0.5%)	9.7 (1.8%)

Table 16. Results of 1998 and 1999 water quality monitoring (Source: Puerto Rico Environmental Quality Board).

On the southwestern coast, clear-cutting of the hillsides surrounding La Parguera has contributed to increased sediment runoff during rainy periods. Additionally, local sewage is discharged into a mangrove channel and reefs may be affected by sewage discharge from upstream sources (e.g., off Guayanilla, Guanica, and Ponce).

Western near-shore reefs are subjected to high turbidity, sediment influx from three rivers, nutrients and sewage from agriculture, the Mayagüez outfall, and tuna canneries. Off Jobos Bay National Estuarine Research Reserve where several fringing reefs surrounding small cays, fore-reef environments have been severely impacted by sedimentation associated with coastal erosion and long-shore transport from the municipalities of Guayama and Salinas.

The Environmental Quality Board (EQB) operates a network of 88 permanent stations around the islands to monitor coastal water quality. Paremeters monitored are for direct human contact (swimming), indirect human contact (sports fishing), and aquatic life (for conservation and propagation of species and marine habitats).The EQB monitored 549.9 shoreline miles, of which 121.9 miles are around Vieques, Culebra, and Mona Islands. Table 15 presents the findings for 1998 and 1999.

EQB results show 97.7% of the Puerto Rican coastline can support aquatic life (defined as 10% or less of the shoreline segment in violation of health standards) and only 1.8% cannot (defined as more than 25% in violation of health standards). For toxic substances, a single significant violation is enough to classify the segment as non-support for aquatic life use. Water quality parameters with the greatest affect on aquatic life along the coastline were turbidity (5.0 miles), ammonia (4.9 miles), and low dissolved oxygen (2.8 miles). These were linked to various contaminant sources, primarily industrial and municipal, sewage disposal, urban runoff, land disposal, and marinas.

In May 2001 the USEPA cited the Bacardi Corporation for Clean Water Act Violations, alleging the company illegally discharged about 3,000 gallons of **mostos**, an industrial waste from its rum processing plant into the Old Bayamon River Channel. This waste is high in certain organic contaminants (e.g., phenols, benzene) and heavy metals (e.g., copper, lead, zinc, chromium, cadmium) that are toxic to coastal wildlife inhabiting mangrove and coral reef habitats (USEPA 2002).

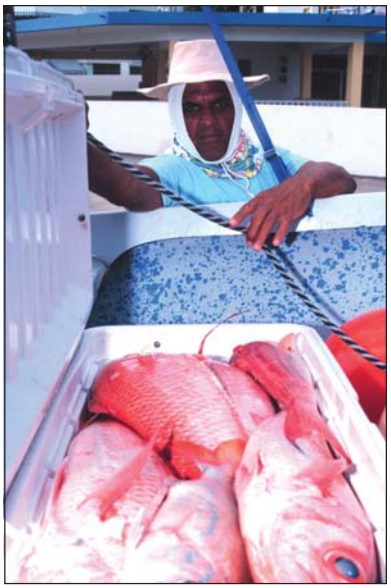


Figure 177. Artisanal fisherman and his catch in the Municipality of Rincon, Puerto Rico (Photo: William B. Folsom).

Coastal Populations and Reef Economics

The population of the Commonwealth was 3.81 million in 2000 (U.S. Bureau of Census 2002). This represents an annual growth of 0.79% and increase of 8.1% over the past 10 years. Of the 78 municipalities, 43 are coastal ones, where the population is 2.3 million. In 10 years, Puerto Rico has had an increase of 130,418 residents along the coasts. According to the Puerto Rico Planning Board (2000), 4.57 million people visited Puerto Rico in 2000, with a total of $2.39 billion spent in the Commonwealth.

Puerto Rico's artisanal and commercial fisheries (Fig. 177) have been declining in recent years Appledoorn *et al*. (1992). In 1996 it was estimated that the ex-vessel value of this fisheries was $7.7 million), but by 2000 it had declined to $6.4 million (U.S. Department of Commerce 2001). This value is only the revenue received by fishermen (ex-vessel value) and does not include the full value of fisheries products or impact on the economy.

Figure 178. Sediment plume on Puerto Rico's northern coast (Photo: NOAA National Ocean Service).

Environmental Pressures on Coral Reefs

Human Stresses – Reefs off the urbanized island of Puerto Rico are subject to the usual problems generated by pollution/nutrients from urban, agricultural, and industrial sources, sediment runoff (Fig. 178), coastal development, and oil and chemical spills. These problems are slowly being brought under control, but a lot remains to be done.

In the 1950s, human activities such as the massive deforestation of mangroves, dredging rivers for sand and of the principal bays for ocean cargo, runoff from large scale agricultural developments in the coastal plain, the building of thermoelectric power plants on the northern and southern shores have degraded the coral reefs.

Ship groundings have damaged reefs over the years. Vessels removed over the past decade give some indication of the number of vessels that have been grounded (Fig. 179). Some have extensively damaged reef structure and associated seagrass habitats (Glynn 1973).

The *A. Regina*, a 109.7 m 3,000-ton car-passenger ferry was removed in 1990 after five years of intensive effort to remove the wreck in an environmentally safe way (G. Cintrón pers. comm.). In 1997, when the *Fortuna Reefer* was removed from a site near where the *A. Regina* ran aground, it compounded the damage done by the grounding. In an old-growth elkhorn coral thicket off Mona Island, it sheared off huge elkhorn coral branches and colonies, and fractured massive brain corals. Damage extended over 30,000 m^2. In the early 1990s, the U.S. Navy completed removing and disposing of a 6,700-ton former target ship (*Ex Brookings*) stranded during Hurricane Hugo in 1988 on a seagrass bed in the Vieques Passage (G. Cintrón pers. comm.). In 1991, the Russian 129 m 2,400-ton *Larissa Reysner* ran aground and was removed from a spur-and-groove reef formation off western Puerto Rico. That same year, the Zapata oceangoing tug *Independence Service* was raised from a 30-foot deep seagrass bed where it had sunk while being towed after grounding and subsequent removal from a nearby reef in the Vieques Passage (G. Cintrón pers comm.).

Other major activities associated with reef degradation include 1) oil spills (Cerame-Vivas 1969); 2) anchoring of large oil cargo vessels (Hernández-Delgado pers. obs.); 3) overfishing (Appledoorn *et al*. 1992), 4) uncontrolled recreational activities (Hernández-Delgado 1992, 1994), 5) eutrophication (Goenaga and Boulon 1991a), 6) thermal pollution (Hernández-Delgado 1992), and 7) military activities particularly at Vieques and Culebra Islands.

The Navy operates a training facility on Vieques Island. Since 1941, a portion of the easternmost end of the island has been used for military training. Since 2001, the Navy has used non-explosive ordnance. Scientific assessments report historical bombing off Puerto Rico's Culebra and Vieques Islands during strategic training activities has caused local destruction of reef structure (Antonnius and Weiner 1982).

Natural Stresses – Damage to coral reefs in Puerto Rico from hurricanes, coral bleaching, coral diseases, and the Caribbean-wide mortality of the

Figure 179. Recovery of a survey launch that flipped over onto a reef in northern Puerto Rico (Photo: NOAA Library).

long-spined sea urchin *Diadema antillarum* (Vicente and Goenaga 1984; Lessions 1984) has been well documented.

Hurricanes normally occur between August and October, and primarily affect the shallow reefs (Fig. 180). Some have been particularly damaging. Hurricane Georges (September 1998) was the worst hurricane since San Ciprian in 1932. It tracked across the center of the island, moving from the southeast coast across the island on a west-northwest path with sustained winds to 185 km/hr and an eye thirty-two km across. Other storms impacted shallow reefs with weaker winds but heavier rains (e.g., hurricanes Hortense in 1996, Marilyn in 1995, and Hugo in 1989).

Physical damage to reefs from hurricanes and tropical storms over the past two decades has been most severe on the eastern coast near Culebra and Vieques (Hugo and Marilyn) and the southwestern coast near La Parguera (Hortense and Georges). Hurricane Georges devastated most of the remaining elkhorn corals scoured other shallow reef environments, blew out seagrass habitats, knocked down mangroves near La Parguera (Morelock *et al.* 2001). Other notable storms impacted shallow reefs with weaker winds but heavier rains (e.g., hurricane Hortense in 1996).

The storm's biggest impact is when the surface wave action fragments the branching corals. The accompanying rains generate run-off, increasing turbidity. But hurricanes may also be beneficial because they fragment the fast growing branching corals that monopolize the substrate and create space for the slower growing, massive species.

Climate Change and Coral Bleaching – Massive coral bleaching occurred in the late 1980s (Buckley-Williams and Williams, Jr. 1987, Goenaga *et al*. 1989, Buckley-Williams and Williams 1988 and 1989) along with elevated sea surface temperatures. The bleaching created permanent damage.

More recently, Desecheo Island reefs experienced a bleaching event. ReefKeeper International reported a high incidence of bleaching (13-29%) on Desecheo Island nearshore reefs during its January 1999 survey.

Current Conservation Management

Mapping – In 2001 NOAA, in cooperation with Puerto Rico DNER, completed mapping coral reef habitats off the main island of Puerto Rico and the islands of Vieques, Culebra, Desecheo, and Mona. Shallow-water digital maps (to about 20 m) have been prepared for 27 levels of habitat types found around the islands (Kendall *et al.* 2001; Fig. 181). The project uses new technologies to correlate monitoring data obtained from remote sensing. Results are integrated in the DNER Geographic Information System (DNER-CZMP/GIS node).

Reef habitats have been mapped using SHOALS Marine LIDAR with AISA Hyperspectral Imagery to locate coral reefs by distinctive characteristics and classification. Bathymetric contour maps and high-resolution habitat classification maps have been generated that include seagrass beds and three types of reef communities contained within the 40 m depth contour and up to 2 km offshore (fringing reefs, hard ground areas or crest reefs, and offshore reefs). These will be combined to develop an underwater 3-dimensional surface reflective model of the area.

Figure 180. Hurricane surf near Arecibo, Puerto Rico. Note the size of the building for scale (Photo: Commander Grady Truell, NOAA Corps).

Research and Monitoring – Research on Puerto Rican coral reefs started in the 1960s and has proceeded at a slow pace until present. Initial qualitative surveys by Almy and Carrión Torres (1963). Glynn *et al*. (1964) and Glynn (1968) provided taxonomic accounts of corals and guidelines for their identification, which stimulated research on aspects of ecology during the 1970s.

The first geographical inventory of reefs of the area was prepared by Goenaga and Cintrón (1979). This work, along with subsequent qualitative surveys of reef geomorphology and community structure (Cintrón *et al*. 1975, Colin 1978, Canals and Ferrer

1980, Canals *et al*. 1983) established criteria for designation of marine areas with coral reef development as Natural Reserves by the government of Puerto Rico.

Intensified utilization of the coastal zone stimulated problem-oriented research involving coral reef communities, which allowed further quantitative characterizations during the late 1970s through the 1990s. Rogers *et al*. (1978) evaluated the impacts of military operations on the coral reefs of Vieques and Culebra on the northeast coast. Subsequent characterizations of coral reef communities in shallow reefs around the islands of Puerto Rico have included fish assemblages as an integral part of the reef community (García *et al*. 1985, Castro and García 1996, García and Castro 1997). A preliminary assessment of the decline in coral reef associated fisheries was prepared by Appledoorn *et al*. (1992).

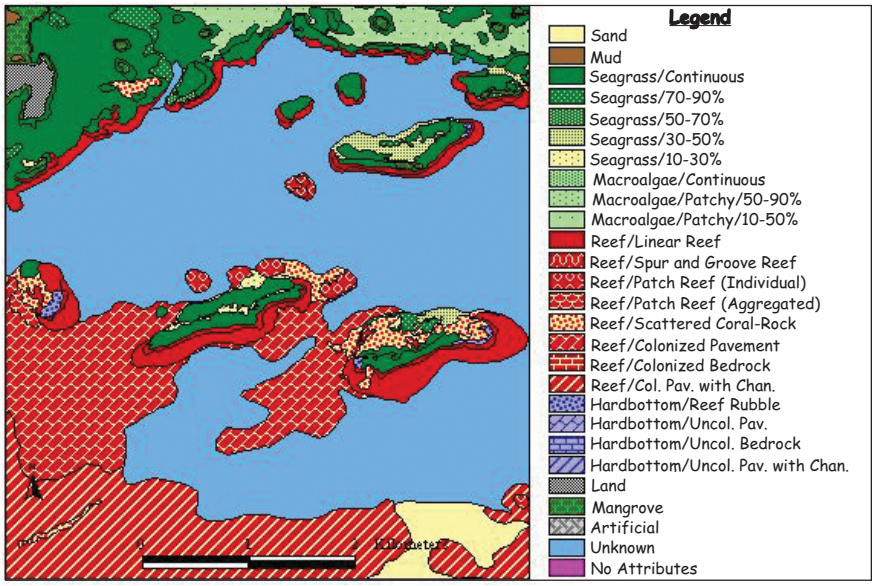
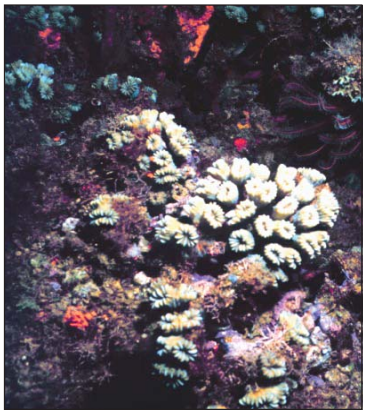


Figure 181. Benthic habitat maps of Puerto Rico were produced by delineating 25 major categories of benthic features (e.g., coral reefs, seagrass beds, mangroves, etc.) based on aerial photographs (Photo: NOAA Ocean Service).

During the last decade, coral reef research in Puerto Rico has largely focused on community characterization and monitoring programs, marine reserve feasibility studies, environmental impact assessments, coral diseases, and mitigation programs. As part of the U. S. Coral Reef Initiative Program for Puerto Rico (with grants administered by NOAA), a series of coral reefs in Natural Reserves of Puerto Rico have been recently selected as priority sites for establishment of characterization and monitoring programs. Baseline characterizations of coral reef communities based on quantitative sampling protocols are available for Jobos Bay (García and Castro 1997; Fig. 182), La Parguera (García *et al*. 1988), Guanica, La Cordillera de Fajardo, El Tourmaline Reef and Caja de Muertos, (García *et al*. 1999). During 2000, baseline characterization studies were underway at Mona Island, Desecheo Island, Boquerón, and La Parguera outer reefs (García *et. al*. 2000). Other initiatives have included characterization efforts in support of the coral reefs occurring within the Rio Espiritu Santo Natural Reserve (Hernández-Delgado 1995), Isla de Mona Natural Reserve (Canals *et. al*. 1983, Hernández-Delgado 1994), and La Cordillera de Fajardo Natural Reserve (Hernández-Delgado 1994).

Figure 182. A baseline characterization was recently conducted for the coral reef community at Jobos Bay (Photo: Jobos Bay NERR).



At least two major efforts were launched during the 1990s to protect reef-associated fishery resources and the ecological integrity of important coral reef systems. A feasibility study for establishment of a Marine Fishery Reserve in La Parguera, southwestern Puerto Rico (García, 1995) included a baseline characterization of sessile benthic and fish communities of the Turrumote, Media Luna, and San Cristobal Reefs.

More recently, on the northeastern side of the island, Hernández-Delgado *et al.* (1998) described the marine biological resources associated with the coral reef at the Luis Peña Fishery Reserve (Culebra Island, Fig. 183). In December 2001, the Puerto Rico DNER completed its initial baseline study at the Luis Peña

Marine Reserve. Seasonally, researchers gathered data on the condition of reef fish and benthic communities from three stations inside the Reserve and com-pared these to results from three coral reef sites adjacent to the Reserve. Data were collected to evaluate the structure of the reef fish and epibenthic communities, coral recruitment, and the density of corals, sea urchins, and territorial damselfish.

Additional quantitative and qualitative characterizations of reef communities have been included as part of environmental impact studies related with the submarine outfall discharges of Regional Wastewater Treatment Plants of the Puerto Rico Aqueducts and Sewers Authorithy from 11 sites around the island of Puerto Rico (García *et al.* 1985). Other characterizations of coral reef communities were performed in relation to operations of thermoelectric thermoelectric power plants in Jobos Bay (Szmant-Froelich 1973), San Juan Bay (García and Castro 1997), and Guayanilla-EcoElectrica (Castro and García 1995, García and Castro 1996).

The Puerto Rico CARICOMP project at La Parguera (Castro and García 1998) monitored fish and motile invertebrates from 1994 through 1998. More recent assessments of motile megabenthic invertebrates and fishes have been included in coral reef community characterization studies sponsored by the U. S. Coral Reef Initiative. These were eight coral reef sites designated as Natural Reserves by the Commonwealth of Puerto Rico (García *et al.* 2001a, 2001b) This work has been coordinated through the Puerto Rican DNER.

With FY00 and 01 NOAA-administered grants, DNER initiated a long-term project to create a network of near-shore monitoring sites that would include coral reefs, mangroves, seagrasses, algal beds, hard bottoms, and other habitats associated with coral reef ecosystems. Additionally, water/substrate monitoring stations were established by DNER in cooperation with the EQB and the Jobos Bay National Estuarine Research Reserve (NERR) Monitoring Program that monitor habitats, disease, and human use of coral reef resources.

Monitoring began in 2000 at three reef sites at locations within nine Coastal Marine Natural Reserves, and in FY01, sites within three more Natural Reserves were added. Parameters monitored are sessile reef communities, motile benthic macroinvertebrates and fishes. Water samples are collected and analyzed for a suite of parameters. To examine temporal variability in water quality and to obtain baseline data, continuous *in situ* sampling is done periodically by deploying for 15 days a submersible instrument that stores measurements of selected parameters (e.g., turbidity, temperature, salinity, pH, and dissolved oxygen). DNER is also using side-scan sonar to characterize the bottom substrata and benthic communities, mainly off the northern and southern coasts of Puerto Rico. This technique will delineate fine-scale habitat structure and use by different species from the shoreline offshore to 61 m. Further, three sediment traps have been installed at each study site to determine contaminant deposition.

Figure 183. Monitoring activities in La Parguera, Puerto Rico (Photo: NOAA Ocean Service).

With additional NOAA grants in FY00-01, coral reef and seagrass bed communities off Vieques Island were characterized at 3 different depths for each of 4 study zones, with 5 replicate transects per depth (a total of 60 transects). Permanent, geo-referenced sites were established for future monitoring of sessile and motile benthic macroinvertebrate populations. Diurnal, non-cryptic, reef fish populations are surveyed at reef and seagrass habitats.

Further, DoD commissioned in FY02 a baseline assessment of coral reefs off the eastern end of Vieques Island. Three 30-m long transects will be taken at each of 18 permanent monitoring sites (6 fringing reef, six bank-reef crest, and six bank-reef slope sites) to evaluate coral species richness and the incidence of coral injury, damage, disease, and bleaching. Baseline coral population data will include cover, abundance, diversity, and community

structure. Censuses of fish populations and sedimentation studies will also be conducted at each reef site. For comparison, three 30-m transects will be taken and similar parameters measured at each of six permanent monitoring sites (two sites each from comparable reef habitats) to assess St. Croix coral ecosystem condition.

Another new project was initiated in 2001. NOAA scientists and local partners (e.g., USGS, NPS, the University of Puerto Rico, and the Oceanic Institute) surveyed reef fish and habitat utilization (Fig. 183). This project is monitoring fish and associated habitats off the main island of Puerto Rico to define species habitat patterns along cross-shelf gradients (Christensen *et al.* in press) and ecologically relevant boundaries for the designation of MPAs off southwestern Puerto Rico.

Since 1994, NOAA has examined the effects of coral diseases and predators on scleractinian corals at sites in La Parguera, Rincon, Boqueron, Aguadilla, and Mona Island. The University of Puerto Rico conducts annual surveys of the red hind population on the western coast of Puerto Rico. Besides collecting data on red hind recruitment, abundance, and genetic make-up, this project also correlates stock size with the condition of the coral reef ecosystem by monitoring benthic cover and species diversity. Other University of Puerto Rico scientists have monitored recruitment, growth rates, and mortality of gorgonians in La Parguera on a semi-annual to biennial basis since 1983.

MPAs and No-take Reserves – The Desecheo National Wildlife Refuge is administered by DoI's USWFS. Numerous Commonwealth MPAs offer various measures of protection for coral reef ecosystems. Territorial MPAs include eight Special Planning Areas and 24 Coastal Marine Natural Reserves. Two new Territorial no-take zones prohibit fishing and anchoring.

In 1999, the Puerto Rico Planning Board established the Luis Peña Natural Reserve as a 4.8-km^2 no-take zone. It is located along the channel separating Culebra Island from Luis Peña Island.

In 2000, the 6.2-km^2 Desecheo Marine Reserve was designated by the Puerto Rico Legislature as Puerto Rico's second no-take zone. It comprises all coastal waters and aquatic ecosystems from the shoreline to 805 m offshore.

The Jobos Bay NERR was established in 1981 and is currently co-managed by NOAA and DNER. In 2000, the Governor approved the Jobos NERR Management Plan. This MPA protects Puerto Rico's second largest estuarine area off the southern coast of the main island and includes a series of mangrove islets that are fringed by coral reefs and seagrass beds. The Jobos Bay NERR is home to several federally-protected endangered species, such as the brown pelican, the peregrine falcon, the hawksbill turtle, and the West Indian Manatee (Fig. 185).

Government Policies, Laws, and Legislation

Puerto Rico's maritime jurisdiction extends offshore 16.7 km from its coastline. Recently, there have been new and revised laws and regulations for the protection of coral reefs, fisheries, and related habitats, the approval of the Non-Point Source Implementation Plan, the Mapping of Coral reefs in Puerto Rico, and an increase in Island's NGOs outreach programs.

Developing regulations in the Commonwealth of Puerto Rico is different from that in the United States where control of development is a local responsibility and coastal management programs are at the state level. Because of its limited size, land use policies in Puerto Rico (including coastal management), are proposed by the Planning Board and approved by the Governor.

With input from the DNER and the EQB, the Planning Board (the Board) has responsibility for overall policymaking and development control. The Board adopted and established a general policy regarding the "...avoidance of urban sprawl" and to "... concentrate industrial development to avoid potential conflicts between uses and protect the environment and natural systems." Agricultural development has a general policy to "...protect

Figure 185. Sea turtle at Jobos Bay NERR (Photo: Jobos Bay NERR).

soils, avoid erosion, protect soil productivity, and avoid adverse impacts on water and other natural resources." The goal of the public policy regarding natural, environmental and cultural resources is "...to maintain and protect our" environment, while promoting conservation, preservation and wise use of our natural, environmental, historical, and cultural resources, recognizing their importance to integrated and sustainable development."

The government agencies responsible for coral reef and marine resources include the DNER, the EQB, the Planning Board, the Regulations and Permits Administration (RPA), and the National Marine Fisheries Service. The DNER manages the coastal zone. The EQB establishes and monitors water quality. The RPA administers the land-use regulations adopted by the Planning Board island-wide. By statute, the RPA works closely with the EQB and DNER.

Guidelines and funding under Section 6217 of the CZMA enabled DNER to prepare the Coastal Non-Point Sources of Pollution Control Plan, approved October 2000 by the NOAA and the USEPA. A Natural Protected Areas Strategy has been prepared and includes a Marine Protected Areas Subsystem, providing guidelines for important coastal area and resource identification, management and protection.

In 1997, a Coral Reef Working Group was formed in the DNER to update the Coral Reef Action Plan. The members are from all government divisions and programs with responsibilities for coral reefs. Together, they produced the DNER five-year Coral Reef Action Plan (1999-2004) with input from U.S. Islands Coral Reef Initiative, the Puerto Rico Costal Zone Management Program, and the University of Puerto Rico Sea Grant Program.

The Action Plan focuses on gathering the necessary information needed to support science, education, monitoring, management, and enforcement, but retains the original objective of addressing the lack of information and adequate management of coral reefs. These have become key points in further developing a more detailed awareness, outreach, and enforcement plan.

Conclusions and Recommendations

The present human pressures on Puerto Rican coral reefs are some of the most critical in the Caribbean (Goenaga and Boulon 1991b). Three of these islands currently support a resident population of over 428 people/km^2. Largely due to accelerated urban and industrial coastal development over the last four decades and the lack of effective implementation of policies to protect the ecological integrity of these resources, many of Puerto Rico's nearshore reefs are degraded.

Between the 1960s and the 1980s, there was only intermittent interest in the reefs and their health. Environmental Impact Statements, required by local law for development along the shoreline, have also generated quantitative and qualitative studies of reef communities, but these mostly relate to underwater outfalls from regional wastewater treatment plants and discharges from conventional thermoelectric power plants. Since the late 1990s, however, scientists and the Government have made a concerted effort to better understand, protect, and manage the reefs.